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Classification of control features related to microgrid operation standardisation

Abstract. *These paper deals with the classification of control system features for microgrids. A microgrid control system development is based on the conventional allocation of the levels to adapt standardized and field-proven structures. As part of alternative approaches the latter are adjusted accordingly. In this paper different control system approaches for a microgrid are presented which can guide or partially influence decentralized system components within their separate control and regulating processes. Generraly, control categories and their characteristics are presented, classified and explained specifically.*

Streszczenie. *Artykuł omawia klasyfikację cech układów sterowania mikrosieci. Opracowanie układu sterowania dla mikrosieci opiera się na alokacji poziomów funkcyjnych, aby dostosować znormalizowane i sprawdzone rozwiązania. Alternatywnie, dotychczasowe rozwiązania mogą zostać zmienione. W artykule zaprezentowano różne spojrzenia na strukturę sterowania mikrosieci, która może nadzorować lub tylko częściowo wpływać na zdecentralizowane komponenty systemu mające autonomiczne procesy kontroli i regulacji. Podsumowując, kategorie cech układów sterowania, zostały zaproponowane, sklasyfikowane i szczegółowo omówione. (**Klasyfikacja właściwości i cech mikrosieci w odniesieniu do standaryzacji procedur sterowania)**.*

Keywords: microgrid, smart grid, standardisation.
Słowa kluczowe: mikrosieci, sieci inteligentne, standaryzacja.

Introduction

Microgrid (MG) is widely discussed subject across power engineering community. A microgrid is a practical solution for areas where the access to public electric grid is technically or economically unattractive. The functionality and application possibilities of microgrids are changing offering new advantages and new business models [1]. A very important prerequisite for further development and practical implementation of MGs is standardisation and common acceptance of functional definitions. Closely related is the need for generally used control and operational algorithms based on commonly accepted MG's structure and MG's control features.

The unprecedented development in distributed generation imposes new challenges on distribution system operation at medium voltage level. A growing number of active components in low voltage and medium voltage grids results in increasing coordination and control efforts taken by distribution system operators (DSO). Various incentives and support mechanisms across Europe contributed significantly to dissipation of distributed electrical power generation ranging from microgeneration at low voltage level up to megawatt installations.

Especially wind and solar generation is characterised by unavoidable short and long term variations. These variations require complex monitoring and control mechanisms to guarantee acceptable frequency and voltage values in the distribution grid. New monitoring and control systems are an emerging research and innovation field across electrical power industry. Traditional functions of the centralised structures as: generation, transmission, distribution, trade and utilisation of energy are radically changing due to decentralisation. The emerging new concept of electrical energy distribution comprises multifunctional participants connected into a complex system [2].

The meaning of microgrid

One promising approach to the mentioned challenges is the minimisation and decentralisation of grids functional elements. The concepts of a *smart grid* (SG) and *microgrid* (MG) continuously gain popularity and publicity. This intelligent small grids or grid units enable an optimised balance between power generation and consumption in a specific area.

Microgrid is not a new invention, in fact it is dating back some decades. The incandescent lamps invented by T. Edison (1879) were fed through a power line seen as a precursor of modern electrical power industry. The first commercial power station was built by T. Edison in Pearl Street in Manhattan in 1882. It is seen as the first realisation of a microrid [3]. Specialised utilities and power delivery companies grew over the years and impeded the development of MGs. The business model of electrical power transmission and distribution was generally based on wide area grids and bulk power stations.

In the current discussion on *interregional smart grids* are MGs an interesting and important issue. The term MG was vaguely associated with the idea of *virtual power plants* and gained some popularity in the 90's. Due to missing standardisation and common definitions there was little precision in this area. Based on the approaches of US energy department [1] and the proposal in [4] a conscience definition can be presented.

A microgrid is a scalable, sustainable, local power grid consisting of electrical and thermal loads and corresponding decentralized generation units with the ability to operate independently of the overlaid grid. Microgrid components here include distributed energy resources (including demand side management, storage and generation), control and management, a secure power grid and communications infrastructure and a secure information management. They are connected via pcc with the overlaid grid.

The above description covers the important features of a microgrid:

- local, closed power network
- consist of the typical grid components: generation, load and storage
- operates as a controllable unit
- physically separable from grid
- grid connected or island operation mode

Properties of microgrids

Lawrence Berkeley National Laboratory (LBNL) has identified useful properties of MGs with the goal of standardisation support [5]. According to LBNL these futures should be considered in research, development, prototyping and standardisation. These are:

- autonomy
- stability

- compatibility
- flexibility
- scalability
- efficiency
- economy
- peer-to-peer model

a closer treatment of these features is given in [2].

Operational modes of MGs

The operational modes were listed with accordance to the power flow controllability in a microgrid. Static modes were characterised along with allowed transitions.

Grid connected operation

The MG is physically connected to a larger grid at point of common coupling (PCC). No assumption is made of the power flaw direction. Usually, the MG is seen as controllable load capable of a bidirectional power transfer, but at a particular time instant there can be no power exchange at PCC. However, the outside network provides information to MG about frequency, voltage level, phase angle, power quality indicia. The outside network has the function of a *master* setting the electrical parameters for the power electronic devices within MG.

Island operation

The *island operation* is sometimes characterised by non-existent power transfer at PCC. More precise definition requires physical disconnection form the outside gird. The operation in this modus can be scheduled in advance or results from abnormal grid conditions.

Transition between grid connected modus and islandic operation

Accordingly to the reasons of disconnection the operational parameters of the outside grid can be transferred to MG internal control algorithms. However, due to different electrical parameter limits in islandic operation an adjustment is necessary. The transition from islandic operation to full grid connection requires additional synchronisation of operational parameters. Both transitions were shown schematically in Fig. 1.

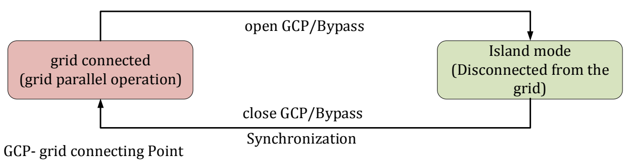


Fig.1. Transition between islandic operation and grid connection of a microgrid

Approaches to control in microgrids

Modern control systems are highly complex, with numerous functionalities implemented. Two aspects are especially important and demanding for the control and protection strategies in microgrids. Power delivery quality and security must remain unchanged, but additionally the advantages of distributed generation should be unrestricted and available. The challenges are rooted in the observation of traditional power delivery systems functional problems, e.g. stability issues [6].

The most important challenges for the control and protection of MGs are [6]:

- bidirectional power flow
- stability issues
- marginal mechanical inertia
- uncertainty

A control system of a MG should cope effectively with those challenges to guarantee an robust and economical operation. Therefore, a MG control system should show following features [6]:

- output control
- power balancing
- DSM/EMS/DR
- economic dispatch
- transition between both operational modes

In case of the paper following abbrevations are used:

- DSM - Distribution-Management-Systeme,
- EMS – Energy Management System,
- DR – Demand Response.

There is no commonly accepted method for the description of control features in a MG, nor generally valid assumptions and terminology. In the literature there are different approaches proposed at various levels in the MG structure. Especially the connection of existing technics and emerging concepts increases the complexity. But an overall descriptive structure is needed for further development of control system structures.

An overview of various control system features and aspects is given in Table 1. Certain degrees of freedom are placed between features of different categories. There is no claim that Table 1 is complete, but it shows the most important aspects of MG control systems.

Some categories and corresponding differences in shaping possibilities are described, following [2].

Table 1: Features and layout of microgrid control categories [2]

Category	Feature and shaping				
control architecture/ control level	market operator/utility service		MG-CC	LC	
Steering level	zero	one	two	three	
Steering concept			central	de-central	
	hierarchic		multi-agent-system		
Operational modus	grid connected		islandic operation		
Control methods			single-master	multi-master	peer-to-peer
Control strategies for electronically connected DER	grid-following-control		grid-building-control		
-non interactive control methods	power export (with/without MPPT)		voltage and frequency control		
-interactive control methods	power-dispatch active and reactive power		load balancing		

Control architectures

The control levels in Fig. 2 emerged following the cell structure of a MG and independently from the control concept. The structure in Fig. 2 enables an overview of components and control levels in a microgrid, but is not defining a control architecture or a control concept. The usage of the term *hierarchic* in the various control areas needs further explanation. *Hierarchic* in this context defines the structure of depending levels. So, the control structure of a microgrid is hierarchically build and fitted with according functionality. Generally, the MG control can be divided into three groups (Table 2).

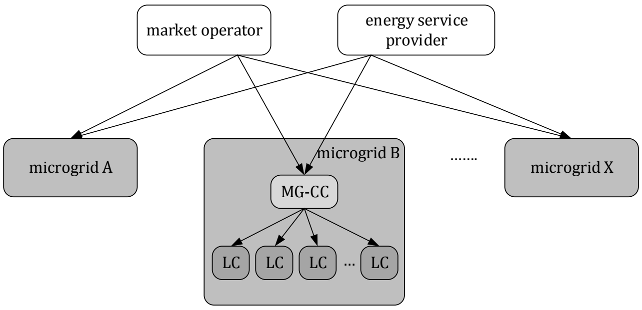


Fig.2. Control levels in microgrid environment, based on [7]

Table 2: Control levels and functions in a microgrid

level	function
market operator/utility service,	resposibility for the technical operation oft he overlaid network, energy service market
MG-CC (Microgrid Central Controller),	Interface between market operator/utility service and the microgrid, funcionality depends on the archtecture
LC (Local Controller).	Control unit of the process components, depending on the control architecture, degree of decentralization and communicative connection corresponding functions

Control level

The Union for coordination and transmission of electricity (UCTE) defines a hierarchic control for bulk power installations. Considering the functionality and features of micrgrids a question from IEC/ISO 62264 standard [8] can be recolled:

How to combine the energetic interactions between microgrid and grid with the internal control systems?

The main goal of the standard set is a conscience terminology provision for the communication between power generation and power delivery subsystems. In order to adjust the standard to microgrids four control levels were proposed (Fig. 3). All these four levels describe the influence of the control on the process and the time scale of the levels as well.

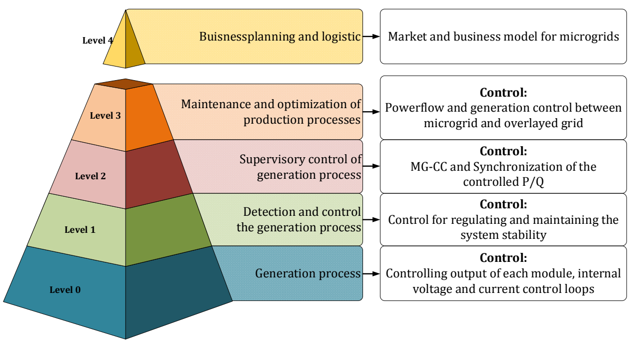
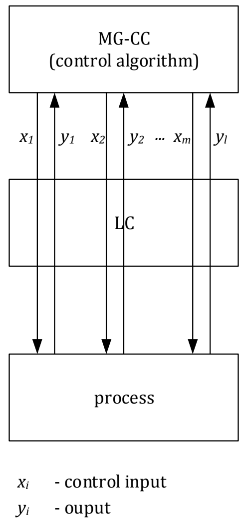


Fig. 3. IEC/ISO 62264 standard level and its application for microgrids [2]

Control concepts

Accordingly to the control levels for MGs various approaches to control concepts can be listed. Within the microgird all or at least one functions and applications subset should be taken by the control system. The objectives of the functions are achieved either by centralized, decentralized or hierarchical supervisory control, which includes the three hierarchical levels: market operator, ESCOs, MG-CC and LC. The different concept forms (centralized, decentralized) correspond primarily with the secondary and tertiary control (Level 2 and 3), as the primary control is in general independent and local (Fig. 4 and Fig. 5). New concepts are based on a multi-agent system that can be assigned to the decentralized or hierarchical control concept in its form (Fig. 6). As basis for all designs, both the central as well as the decentralized approach can be taken.



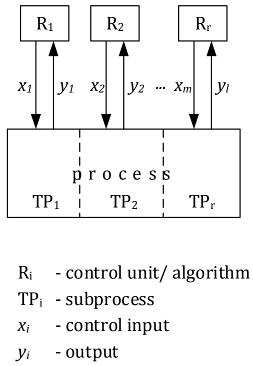


Fig. 4. Central control [2]

Fig. 5. De-central control [2]

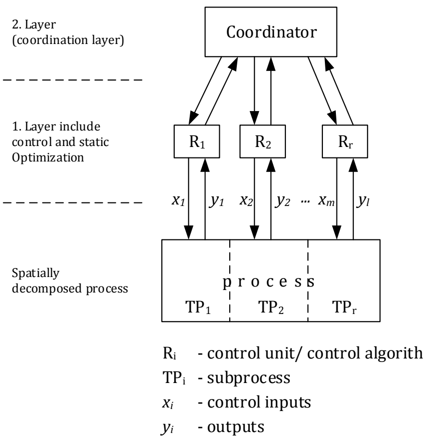


Fig. 6. Hierarchic control [2]

Control methods

The control methods describe the concept of voltage and frequency setting. According to Table 1, various approaches are possible especially in islandic operation. The overlaid network defines as master voltage and frequency in grid connected mode and in parallel mode. There are different methods in isolated operation. In case of an intentional islandic operation, the overlaid network can be used as master for voltage and frequency regulation. This would mean a quick return synchronization when reconnecting to the overlaid network. Furthermore, there is the possibility of a master-slave structure. Here, a MG component sets the voltage and frequency reference values to be followed by the remaining components. The result is based on computer and server architectures with the distinction between a multi-master (dynamic) and single-master structure (static). In dynamic structures the abolition of the Masters brings a function change of another IED from slave to master. In static systems only a single master exists, in case of failure there is no further operation in island mode. Another approach is the distributed voltage and frequency control using local measurements at each IED. The problem here are any oscillations through the control-related inertia, so that a permanent oscillations remain. Based on this approach, depending on the control category the corresponding control feature of the MG can be defined.

Employment and realization

The knowledge of this work finds application in the control system of the university MG BTU Cottbus – Senftenberg (Germany). In this, the interaction between conventional and renewable generators, battery storage and charging infrastructure with electric vehicles is examined by a control system. Based on Table 1 found in this microgrid following control structure application:

Table 3: Control levels and functions in a microgrid

Category	**Feature and shaping**
control architecture/ control level	hierarchic (MG-CC, LC)
Steering level	hierarchic (Level 0, 1, 2, 3)
Steering concept	hierarchic (Level 2 – de-central)

Fig 7 shows a systematic classification of control relevant categories in the specific MG BTU.

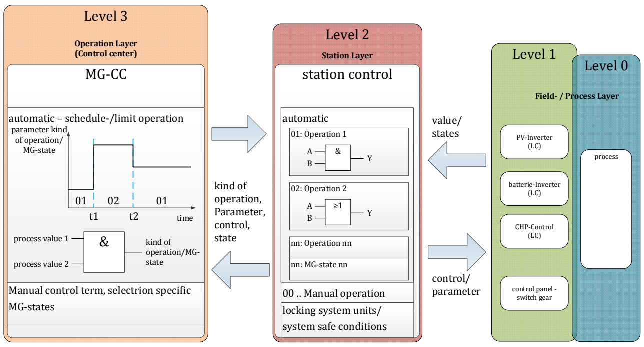


Fig 7: Control hierarchy MG BTU

More information to this project is linked under https://www.youtube.com/watch?v=5d1im8toiqw and http://www.smartcapitalregion.de.

Conclusion

With the definition of microgrids, their operational modes and properties the classification and definition of possible control features and categories becomes feasible. There is no common terminology in this field. These definitions and classifications are the basis for construction of control systems and their incorporation into microgrid structures. However, there is no redefinition or new definition but an application of established approaches within a new scope and in new structures. Other approaches to control of microgrids provide multi-agent systems. They are used as an implementation framework for fixing software - hardware issues.

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